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Comparison of forecast backgrounds of different resolution with surface observations

by
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Introduction

The Meteorological Office unified forecast/climate model (Cullen, 1993) is run at three different resolutions to provide numerical weather forecasts. Each version makes use of observations to initialize the forecasts. Data from the observation system contains two types of error :-

i) Natural error - instrument error,
small scale fluctuations (representivity error).

ii) Gross error - improperly calibrated instruments,
incorrect registration of observations,
incorrect coding of observations,
telecommunication errors.

An accurate description of the forecast and observation errors is necessary for the quality control and assimilation of observations. Ingleby and Bromley (1989) examined the forecast error structure of upper-air winds for two models of different resolution by comparing them with radiosondes. They found surprisingly little difference in the variances and horizontal scales. Intuition and preliminary evidence suggested that surface variables are likely to be more sensitive to model resolution. Hence, it seemed appropriate to study 'Observation - Background' (O-B) differences for surface land stations throughout the UK, taking different models, variables and time periods into account. Another interesting aspect is the extent to which O - B differences are normally distributed.

The three models used by the Meteorological Office are :

1. GLOBAL MODEL - aprrox. 90 km grid length

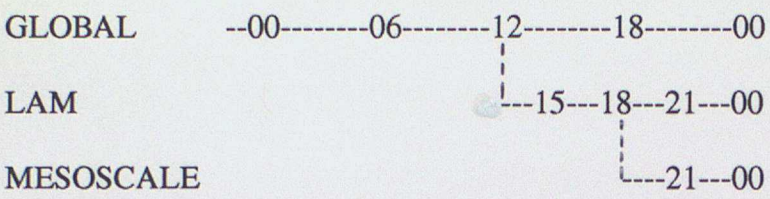
2. LIMITED AREA MODEL (LAM) - 45 km grid length, North Atlantic and Europe

3. MESOSCALE MODEL - approx. 15 km grid length, UK and environs

Data for the Mesoscale model were only available from mid-February 1993.

The diagram below illustrates the assimilation cycles of all three models starting at 00Z. The Global model runs continuously with a 6 hour cycle. At 12Z the analysis from the Global model becomes the initial conditions for the LAM and at 18Z the analysis from the LAM becomes the initial conditions for the Mesoscale model. These latter two models have

a 3 hour assimilation cycle.



The most complete coverage of observations occurs at 00Z and 12Z for surface land stations, and since the Mesoscale model is most spun up at 00Z, all data used in the study were those recorded at this time.

Procedure

Data concerning the 'observation - background' differences for pressure, measured in millibars at surface land stations (SYNOP's) throughout the UK during the months listed below, were extracted from the Observation Processing Database (OPD). A SAS dataset was then created to include any observations which had not been rejected by the background and the buddy check. This resulted in samples of approximately 30 for each SYNOP, from which the following statistics were calculated :-

- *mean*
- *standard deviation*
- *skewness*
- *kurtosis*

The statistics were then plotted at their station locations on a map of the British Isles and in each of the four cases, an overall value was obtained to two decimal places.

The above procedure was repeated for :-

a) each forecast model
- *Global*
- *LAM*
- *Mesoscale*

b) different months
- *September 1992*
- *December 1992*
- *March 1993*
- *June 1993*

c) other variables
- *Temperature*
- *Wind components u (Westerly) and v (Southerly)*
- *Relative humidity*

The summary statistics and maps were studied and any patterns or unusual features recorded. In particular, differences amongst stations situated at proximity were noted and monthly standard deviations were plotted against grid length.

Results

Below are summaries of the main characteristics noted for the selection of months, models and variables studied. The actual figures obtained can be viewed in Appendix A.

Pressure

September 1992

Global Model -

The overall mean pressure is 0.05 with the highest values occurring inland. The largest absolute mean is -1.8 from a SYNOP located in the Shetland Isles, Callsign 03007. This station also gives the largest standard deviation of 2.9. Negative skewness is apparent in Southern Scotland and along the East Anglian coastline. Values of kurtosis over 7.0 are present in Southern Scotland.

LAM -

The mean error and standard deviation have increased to 0.55 and 1.09 respectively from the global model whereas kurtosis and skewness have both been reduced. The errors appear to be higher over the Pennines and Scottish mountains and skewness is negative throughout the UK.

December 1992

Global Model -

Higher standard deviations are apparent in Scotland and skewness is close to zero in the Devon and Essex regions.

LAM -

The overall mean error and standard deviation have decreased, whereas skewness and kurtosis have increased. High kurtosis is present in Northern Scotland, reaching values of 5.1 and 6.3. In the South of England the kurtosis is negative.

March 1993

Global Model -

Mean errors appear to be smaller in coastal regions. The highest mean error is 2.4 in South East England, Callsign 03695. Extremely high values of kurtosis, ranging from 2.5

at station 03895 to 7.4 at station 03781, are located South of a line drawn from London to Bristol.

LAM -

Negative mean errors in South East and North East England, Cumbria and the Scottish Islands. Values of kurtosis have been significantly reduced from the global model.

Mesoscale Model -

Mean errors have been reduced further and standard deviations and skewness are very similar to the LAM. The Mesoscale model, however, gives the highest overall kurtosis of the three models at 1.47. There is a negative bias in Southern England and the West country, and an outlying value for kurtosis is 9.1 at station 03745 in the South. Stations situated close by give kurtosis at 1.6, -0.8 and 0.4 making this particular observation even more unusual.

June 1993

Global Model -

Most of the mean errors are positive and close to zero. The overall skewness is 0.07 and the standard deviations are all less than 1.0. One extreme value of kurtosis is 7.57 calculated from the sample at station 03872 and located in the centre of the South coast.

LAM -

All statistics have been reduced, implying more accurate forecasts.

Mesoscale Model -

The overall mean error has increased in absolute value from -0.04 to -0.19. The standard deviation and skewness have both decreased. Outlying mean errors in Scotland have decreased for example at station 03063. Previous models gave 'observation - background' differences of 0.8 and 0.7 respectively. With the Mesoscale model this figure is now 0.1.

Temperature

September 1992

Global Model -

Mean errors are higher in the South east of England with values ranging from 3.0 to 3.9. Slightly higher standard deviations are apparent in central Scotland and a few extreme values of kurtosis present in Ireland. However, overall kurtosis is 0.75.

LAM -

In the global model, the overall mean error was 1.31 and this has been reduced to 0.75. Errors appear to be larger in central areas than in coastal regions. The standard deviation is also lower at 1.57, reduced from 1.86 in the Global model. At a glance, the deviations look slightly higher in the west of the country. Skewness seems to be clustered in positive and negative groups throughout the UK. Kurtosis is 1.10. The highest kurtosis is 4.7 at a station in South West Scotland, Callsign 03132, although other high values for this statistic, between 2.0 and 4.6 are present in the Shetlands.

December 1992

Global Model -

The overall mean error is 1.58, slightly higher than that for September, and the standard deviation is 3.01, whereas skewness and kurtosis are close to zero. There are stations with large mean errors in Southern England which have small standard deviations, and negative errors occur in coastal regions and the Scottish Isles.

LAM -

Large mean errors are present in central England with values of 3.9, 4.1 and 5.9, but the overall mean is 1.10. The overall standard deviation is 2.48 which is still quite large and the highest standard deviation is 3.9 from a station, 03065, in Northern Scotland. Skewness is less than 1.0 in nearly all cases and kurtosis appears higher in Scotland and Ireland.

March 1993

Global Model -

There are numerous large mean errors over, 3.0 in absolute value, at stations from Yorkshire downwards. The standard deviation is 2.35 with an outlier of 3.3 in Scotland. Skewness and kurtosis are close to zero overall. Unusually high kurtosis of 4.0, 5.3, and 5.9 was calculated for stations 03302, 03204 and 03203 respectively.

LAM -

Largest mean errors are 4.01, Callsign 03791, and 4.65, Callsign 03779. the overall mean and standard deviation have been reduced from the previous model. There is an outlying standard deviation of 3.2 at station 03065 in Scotland and high values of kurtosis are present in Ireland and the Shetlands.

Mesoscale Model -

There are higher mean errors along a line drawn from Bristol to London and in the Midlands. Kurtosis reveals outliers of 8.097 and 7.007 at stations 03469 and 03162 situated in the Wash and Southern Scotland respectively.

June 1993

Global Model -

Highest standard deviations in Wales and central England. High kurtosis in the shetlands but otherwise statistics are close to zero, consistent with normality.

LAM -

Overall mean is 0.28 which is much lower than the Global model at 9.0. There is an outlying standard deviation of 4.2 in Wales, Callsign 03503.

Mesoscale model -

Overall mean error has increased slightly to 0.42. Kurtosis has also increased to 1.58 and it reaches 6.0 off the North west coast of Scotland.

Wind Component u

September 1992

Global Model -

Except for the South Coast of England, the mean errors are negative and the most extreme value is 3.0 at Callsign 03065 in Scotland. The overall standard deviation is 2.43 and the outliers are coastal or situated in Scotland, with the largest being 5.5 at station 03065. The skewness is close to zero throughout the country and kurtosis is less than 1.0 in most cases.

LAM -

The overall mean error has increased in absolute value from the global model. There are two outliers of 3.1 and 3.3 in Scotland. Overall the standard deviation has increased to 2.49 and large errors can be seen along the South Coast of England, in North Wales, Northern Ireland and Scotland. Skewness is 0.02.

December 1992

Global Model -

There are extreme mean errors in the far North of Scotland and many errors are negative. There also appears to be a slight increase in error in the North West of the UK compared with the South East. The average standard deviation is larger than for September and high values between 3.5 and 6.5 are dominant in Scotland and parts of Wales. Along lines of latitude skewness is similar and one unusual value for kurtosis is 15.5 which was measured at station 03488 in East Anglia.

LAM -

The overall mean is similar to the above model and errors appear slightly higher in Scotland and Ireland. High standard deviations occurred in the Shetland Isles, Northern Scotland, Cumbria, Merseyside and parts of Ireland.

March 1993

Global Model -

The mean errors are mostly negative throughout the UK. There is an outlier of 4.3 at Callsign 03065 and another of -3.4 at Callsign 03174. High standard deviations are present in Northern parts of England and Scotland. The largest is 5.6 at Callsign 03065.

LAM -

The mean errors again appear to be higher in North Scotland, England and Ireland. The highest standard deviation is 6.7 at station 03065. Skewness and kurtosis are low and nothing seems unusual.

Mesoscale Model -

The overall mean error has been reduced from the LAM to -0.25. There are outliers in Scotland of 5.3, Callsign 03065, and 4.3, Callsign 03041. Standard deviation has also been significantly reduced. However, skewness and kurtosis have increased, the latter statistic to a figure of 3.88.

June 1993

Global Model -

The overall mean of -0.61 illustrates the increase in negative errors compared with previous months and models. Callsign 03011 gives an outlier of -3.6 and Callsign 03041 has a large mean error of 3.1. Both of these stations are situated in Scotland where standard deviations are also higher. Coastal regions seem to produce lower standard deviations. Skewness and kurtosis are close to zero.

LAM -

Mean errors are higher in Scotland and Ireland with an outlier at station 03011 of -3.1. The standard deviation has decreased further from the Global model and the previous month.

Mesoscale model -

The overall mean error is now -0.22 and the overall standard deviation is 1.80. The most extreme deviation is 6.6 from station 03065. Skewness is 0.02 suggesting a nearly symmetrical distribution of O - B differences. There are outlying values of kurtosis in the

Channel Islands of 5.2, station 03894, and 6.4, station 03895. Station 03014 in the Shetlands also reveals a high kurtosis of 4.5.

Wind Component v

September 1992

Global Model -

The largest mean error is -3.4 at Callsign 03340 near Manchester, although this station has a standard deviation of 0.0. Large standard deviations are found around the Irish coast and in Northern parts of England and Scotland. Overall it is 2.43. Callsign 03011 has an outlying value of 5.9 for kurtosis.

LAM -

Mean errors seem to have a more positive bias in England compared with the rest of the UK. Standard deviation increases in Scotland, Ireland and along parts of the South coast.

December 1992

Global Model -

There are negative mean errors throughout the country falling as low as -3.1 at station 03960 in Ireland, and -3.3 at station 03114 in Scotland. There appear to be high standard deviations in Scotland and coastal areas. North West Scotland and Northern Ireland give extremely high figures for kurtosis of 9.22 at 03111 and 8.82 at 03920 respectively.

LAM -

Standard deviation has values over 3.0 in Northern and Western parts of the UK. Outlying mean errors occur in Scotland, Wales and Northern Ireland. In particular, the error is -3.2 at Callsign 03140 and -3.0 at Callsign 03114. There does not appear to be anything unusual about the skewness or kurtosis.

March 1993

Global Model -

No outlying mean errors are present but there are high standard deviations in Scotland, 6.54 at Callsign 03065, and areas of Northern England. The overall standard deviation has decreased from 2.80 in December to 2.64. High kurtosis of 4.7 and 5.4 is apparent in the Shetlands and North East Scotland.

LAM -

There are a couple of mean errors over 2.0, mainly in Scotland, Ireland or along the South coast. High standard deviations are present in Scotland, Ireland and the South West coast. Kurtosis is 5.8 in the Shetlands but otherwise close to 1.0.

Mesoscale Model -

There is an outlier in Scotland with mean error of 4.0, Callsign 03041. Other mean errors are negative and mostly less than 1.0. The highest standard deviations are 4.74, station 03041, and 6.36, station 3065. Skewness seems okay but there are two exceptionally high values of kurtosis, 8.55 at station 03092 on the coast of North East Scotland and 16.0 at station 03955 on the coast of Southern Ireland.

June 1993

Global Model -

Two mean errors outlying in Scotland are 2.21 from station 03790 and 5.66 from station 03041. There are also high standard deviations in Scotland, namely 4.04 at Callsign 03057 and 5.159 at Callsign 03065. Skewness is negative on the mainland but mostly positive in Ireland. Highest kurtosis is 4.33 from station 03132 on the South West coast of Scotland.

LAM -

Mean errors and standard deviations are again larger in Scotland. Station 03340 has a standard deviation of 0.0.

Mesoscale Model -

The number of large mean errors and standard deviations has been reduced from the LAM. Skewness is very close to 0.0 in many cases and the overall standard deviation is 1.78, which is the lowest for all months and models for this variable.

Relative Humidity

(No data were available for the global model.)

September 1992

LAM -

For some stations the mean errors are small, under 1.5, yet for the majority they range from 3.0 to 8.2 in absolute value. The overall standard deviation is 7.33. However, at station 03214 in Cumbria, it reaches 18.1 and the kurtosis here is 17.1. The sample size is 27 observations and the station height is 15 metres, which are not unusual at all.

December 1992

LAM -

The overall mean is -4.26. The lowest errors are in Ireland and central parts of Scotland and England. The standard deviation has increased all over the UK since September, the highest figure being 11.6 at Callsign 03006 in the Shetland Isles. Skewness and kurtosis appear normal apart from a few outliers for kurtosis on the North West coast of Scotland, 8.3 at station 03100 and 8.2 at station 03111.

March 1993

LAM -

The overall mean error is -6.80. The errors are slightly lower in Western parts of Scotland and Ireland. The standard deviation is 9.15 but skewness and kurtosis are close to zero. Callsign 03006 gives a very large standard deviation of 14.6.

Mesoscale Model -

The mean error has been reduced to -5.82 and in Scotland and Ireland especially, the errors appear smaller. The standard deviation is also slightly smaller than that for the LAM. Skewness has become more negative and kurtosis is close to 0.0 in nearly all cases apart from a few outliers, the largest being 8.4 at station 03100.

June 1993

LAM -

The overall mean error has decreased dramatically from previous months and models to -2.44. There are even a couple of stations registering 0.0. Standard deviation is still quite high though, the largest values being 12.45 at 03726 and 12.50 at 03749. Kurtosis reveals outliers of 8.2 at station 03102 and 13.4 at station 03100.

Mesoscale Model -

The mean error has increased to -4.18 but the standard deviation is slightly smaller than the LAM at 7.62. Skewness is slightly higher and appears to increase in Northern Ireland, North West England and along a line from London to Bristol.

Analysis of Results and Conclusions

The statistics suggest that the accuracy of a particular sample of O - B differences depends upon :-

- the model resolution
- the time of year
- station type
- station location
- station height
- sample size

Model Resolution

Figure 1. shows plots of standard deviations against grid length for four out of the five variables studied. The Mesoscale, LAM and Global models are represented on the horizontal axis by the grid lengths 15 km, 45 km, and 90 km respectively. Tabulated values can be found in Appendix A.

Pressure -

the LAM is more accurate than the Global model for all months studied except September 1992. The mesoscale model appears to improve the accuracy further. The standard deviations are smaller for all models in June 1993 and higher deviations are present for the Winter months when the weather is less stable. This could account for the high figure for September, since the pressure was below normal everywhere and South Easterly winds brought thundery showers and storms to the Midlands and South East of Britain.

Temperature -

for each month the LAM is more accurate than the Global model and the Mesoscale model is more accurate than the LAM. The lines for both June 1993 and September 1992 are very close together and situated below the other lines illustrating smaller standard deviations for these months.

Wind Component u -

it appears that a Global resolution of 90 km is a better model than the LAM for all months except June 1993. There is a dramatic difference in accuracy between the LAM and the Mesoscale model.

Wind Component v -

this time the LAM is a better model for December 1992 as well as June 1993. The lines for March and September still reveal improved accuracy using the Global model as a background.

Relative Humidity -

March 1993 had significantly higher standard deviation than the other months. The Mesoscale model modestly improved the accuracy of the forecast compared with the LAM.

As can be seen, all plots reveal a steeper line between the LAM and the Mesoscale grid lengths. The basic shape of each monthly line and its location compared with the others is similar for pressure, temperature and wind. The only exception is for September 1992.

In the case of wind components, the better performance of the mesoscale model is largely due to improved specification of roughness length, and for temperature it is probably due to assimilation of surface temperatures and increased model resolution (B Macpherson, personal communication).

It thus seems reasonable to conclude that although the Global model and LAM produce similar standard deviations those for the LAM are slightly smaller in general, whereas the Mesoscale definitely reduces them and so improves the accuracy of the forecast.

Out of all the variables, pressure seems to be least sensitive to model resolution.

Location of Errors

The standard deviations are also smaller when a particular variable is more stable. The background models are less accurate during the Winter for pressure, temperature and wind and less accurate during the Summer for relative humidity.

Most gross variable errors appear to come from automatic weather stations particularly those which are also located in regions of high terrain such as Scotland and Wales. Weather stations in coastal areas, the Shetlands, and Northern Ireland also produced unusual statistics for all variables and months analysed.

Figure 2. consists of a plot of standard deviation against the longitude of the station for which it was calculated, for the variables pressure, temperature and the two wind components.
The model used was the LAM for June 1993 so that the mean errors and standard deviations were as low as possible without there being a dramatic increase in skewness or kurtosis.

The plots reveal that there is no specific pattern to the way the standard deviations are distributed from West to East. However, for pressure alone, there appears to be a slight negative gradient to the cluster of points which would perhaps indicate an increase in errors in the West. A few interesting stations can be singled out as being the least accurate and the most accurate for this month and model. They are Callsign 03503 in Wales with standard deviation of 4.2 for temperature, Callsign 03065 in Scotland with standard deviation over 5.0 for both wind components and station 03340 near Manchester with standard deviation of 0.0(?). The higher pressure errors in Northern Scotland and Ireland could be linked to the prevailing Westerly winds coming across the Atlantic where data are sparse, but this is open to discussion.

Normality of Errors

Figures 3-6 illustrate the mean, standard deviation, skewness and kurtosis for each sample of pressure errors at SYNOP's throughout the UK. The background used is the Global model and the observations are from September 1992.

If the O - B differences are normally distributed at each SYNOP, the skewness should read as 0.0 and the kurtosis should also be 0.0 (the SAS package subtracts 3 from the normalised fourth moment). For a discussion of these higher moments and also normality in meteorological variables see Brooks and Carruthers (1953).

In general, as the model resolution increases, the mean error and standard deviation tend to decrease, whereas the skewness and kurtosis increase. (The kurtosis is given by μ_4/σ^4 - 3 where μ_4 is the fourth moment and σ the standard deviation. The increase in kurtosis is not necessarily due to an increase in μ_4, but implies that σ^4 is decreasing more than μ_4.) All variable errors have a skewness close to zero but there does not seem to be a definite pattern for kurtosis. Pressure gives the most stable figures for this statistic followed by temperature, wind and finally, relative humidity. At first glance, it would appear that the kurtosis is positive, thus implying longer-tails than the normal distribution. However, as, for example, figure 6. shows, this is not the case for the country as a whole. Here, the kurtosis in the far North and South is consistent with a normal distribution, but a band of higher kurtosis can be seen stretching across Southern Scotland and Cumbria. Looking back at figures 3 and 4, the values for the same region show a negative bias in mean errors but nothing unusual about the standard deviation.

If the errors at each SYNOP are normally distributed, then the distribution of errors nationwide should also be normal by the Central Limit Theorem. Even if the data at each station were not normal, but from some other distribution, the mean errors for the whole of the UK should still be normal asymptotically. The overall statistics calculated do not always reflect this since they are extremely sensitive to outliers. Therefore, it would perhaps be beneficial to use more robust methods when summarising the data in order to recognize the distribution.

The results suggest that the distribution of errors is approximately normal but becomes somewhat longer tailed as the model grid length decreases. This is largely attributed to errors in the forecast model but observational errors/difficulties in quality control may also play a part.

References

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APPENDIX A

SUMMARY STATISTICS FOR PRESSURE

MEAN ERROR

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	0.05	0.55	----------
DEC '92	0.56	0.34	----------
MAR '93	0.74	0.18	0.18
JUN '93	0.07	-0.04	-0.19

STANDARD DEVIATION

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	0.97	1.09	----------
DEC '92	1.06	0.98	----------
MAR '93	0.90	0.78	0.67
JUN '93	0.74	0.73	0.64

SKEWNESS

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	-0.39	-0.17	----------
DEC '92	-0.32	0.51	----------
MAR '93	-0.09	0.29	0.27
JUN '93	0.04	-0.10	-0.31

KURTOSIS

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	1.59	0.49	----------
DEC '92	0.64	2.05	----------
MAR '93	0.68	0.78	1.47
JUN '93	0.47	0.49	0.67

SUMMARY STATISTICS FOR TEMPERATURE

MEAN ERROR

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	1.31	0.75	----------
DEC '92	1.58	1.10	----------
MAR '93	1.57	1.32	0.82
JUN '93	0.90	0.28	0.42

STANDARD DEVIATION

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	1.86	1.57	----------
DEC '92	3.01	2.48	----------
MAR '93	2.35	2.03	1.47
DEC '93	1.84	1.57	1.30

SKEWNESS

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	-0.22	-0.46	----------
DEC '92	0.24	0.32	----------
MAR '93	-0.04	-0.02	-0.11
JUN '93	-0.02	-0.13	-0.22

KURTOSIS

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	0.75	1.10	----------
DEC '92	-0.06	0.30	----------
MAR '93	0.15	0.48	1.30
JUN '93	0.38	1.07	1.58

SUMMARY STATISTICS FOR WIND COMPONENT U

MEAN ERROR

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	-0.87	-0.94	----------
DEC '92	-0.98	-0.97	----------
MAR '93	-0.80	-0.68	-0.25
JUN '93	-0.61	-0.51	-0.22

STANDARD DEVIATION

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	2.43	2.49	----------
DEC '92	2.66	2.72	----------
MAR '93	2.59	2.61	2.00
JUN '93	2.31	2.25	1.80

SKEWNESS

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	-0.08	0.02	----------
DEC '92	-0.05	0.05	----------
MAR '93	0.13	-0.09	0.27
JUN '93	-0.08	-0.16	0.02

KURTOSIS

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	1.07	1.03	----------
DEC '92	1.55	0.17	----------
MAR '93	1.67	1.82	0.27
JUN '93	0.68	0.62	2.19

SUMMARY STATISTICS FOR WIND COMPONENT V

MEAN ERROR

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	-0.45	-0.55	----------
DEC '92	-0.63	-0.73	----------
MAR '93	-0.62	-0.77	-0.29
JUN '93	0.11	-0.10	-0.06

STANDARD DEVIATION

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	2.43	2.48	----------
DEC '92	2.80	2.72	----------
MAR '93	2.64	2.67	2.17
JUN '93	2.25	2.20	1.78

SKEWNESS

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	0.01	0.06	----------
DEC '92	-0.49	-0.20	----------
MAR '93	0.01	-0.07	0.26
JUN '93	-0.12	-0.01	0.05

KURTOSIS

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	1.30	0.79	----------
DEC '92	2.08	0.07	----------
MAR '93	0.83	0.85	2.14
JUN '93	0.60	0.76	1.96

SUMMARY STATISTICS FOR RELATIVE HUMIDITY

MEAN ERROR

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	----------	-2.24	----------
DEC '92	----------	-4.26	----------
MAR '93	----------	-6.80	-5.82
JUN '93	----------	-2.44	-4.18

STANDARD DEVIATION

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	----------	7.33	----------
DEC '92	----------	7.89	----------
MAR '93	----------	9.15	8.47
JUN '93	----------	7.97	7.62

SKEWNESS

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	----------	-0.49	----------
DEC '92	----------	-0.21	----------
MAR '93	----------	-0.23	-0.38
JUN '93	----------	-0.70	-1.02

KURTOSIS

MONTH	GLOBAL	LAM	MESOSCALE
SEP '92	----------	4.94	----------
DEC '92	----------	0.92	----------
MAR '93	----------	0.48	0.50
JUN '93	----------	1.82	2.38

Figure 1.

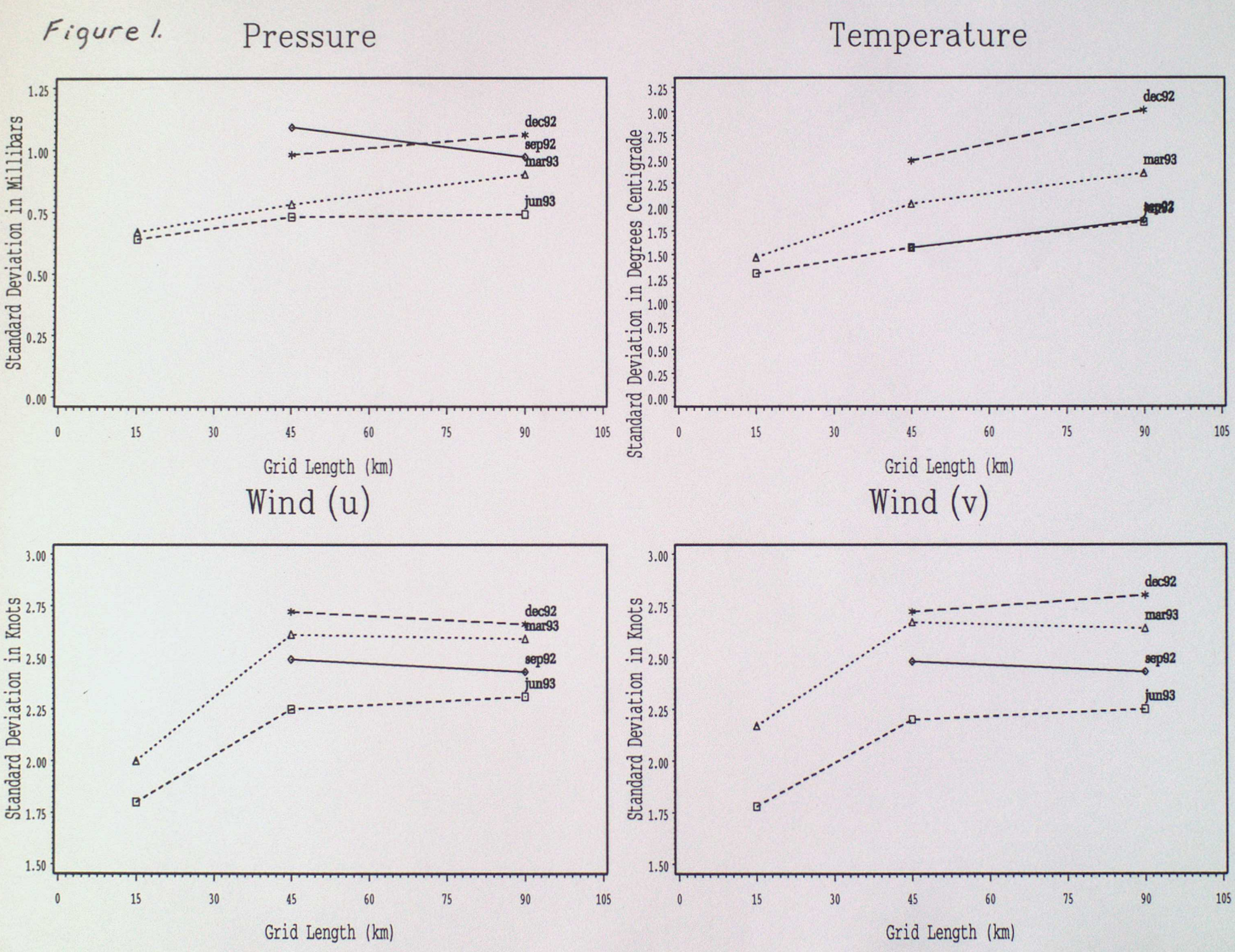
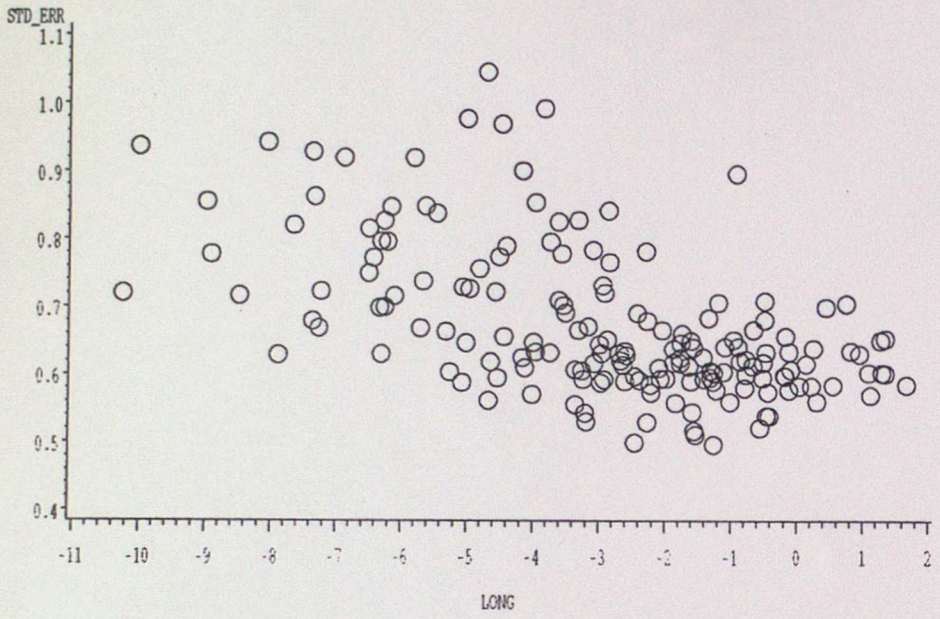
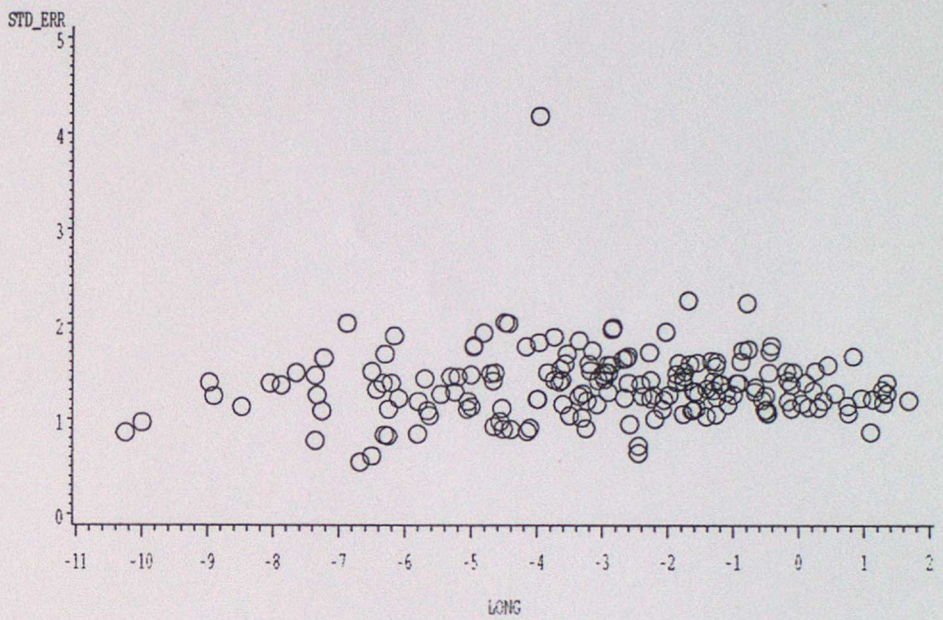

Pressure
Standard Deviation in Millibars
1.25
1.00
0.75
0.50
0.25
0.00
dec92
sep92
mar93
jun93
0
15
30
45
60
75
90
105
Grid Length (km)
Temperature
Standard Deviation in Degrees Centigrade
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
dec92
mar93
sep92
Grid Length (km)
Wind (u)
Standard Deviation in Knots
3.00
2.75
2.50
2.25
2.00
1.75
1.50
dec92
mar93
sep92
jun93
Grid Length (km)
Wind (v)
Standard Deviation in Knots
dec92
mar93
sep92
jun93
Grid Length (km)

Figure 2.

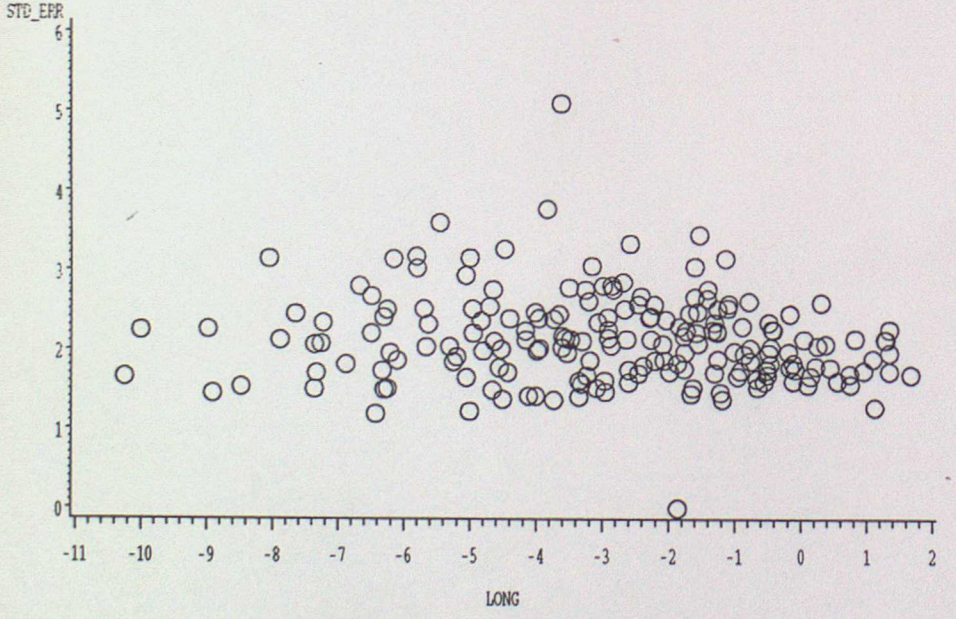
Pressure



Temperature



Wind (u)



Wind (v)

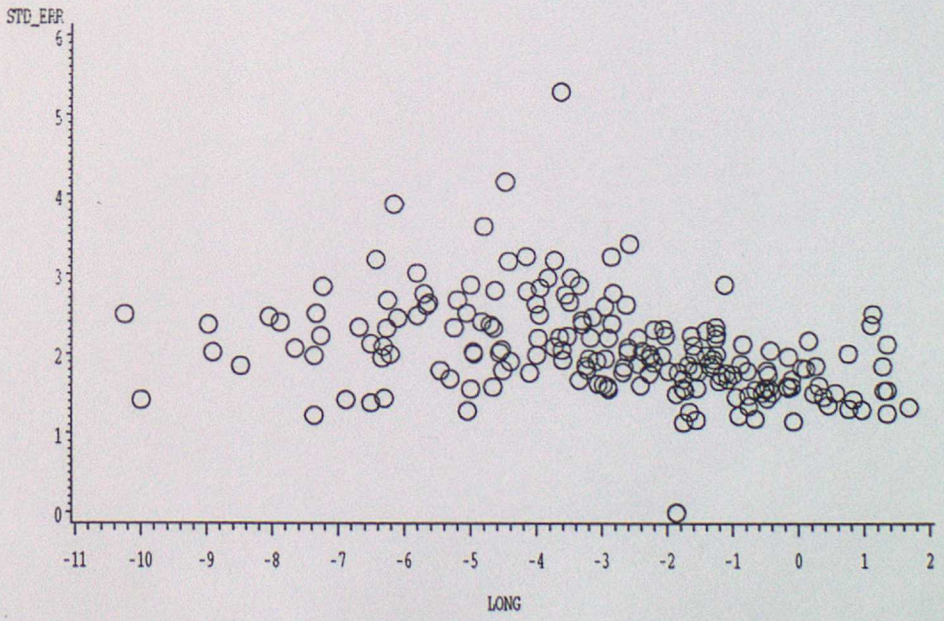


Figure 3.

Global Model : September 92 : Pressure

mean = 0.05

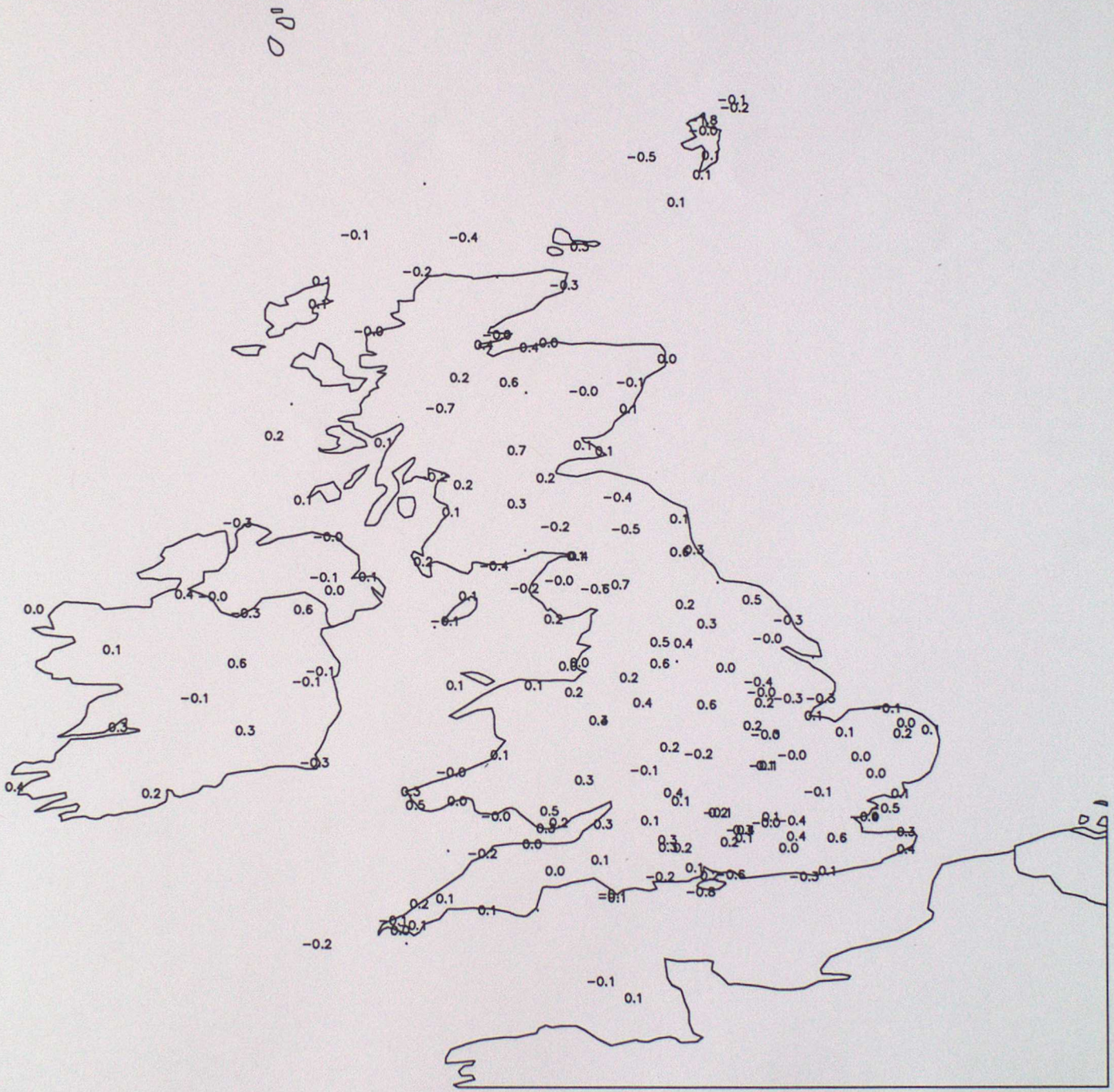


Figure 4.

Global Model : September 92 : Pressure

st. dev. = 0.97

Figure 5.

Global Model : September 92 : Pressure

skewness = −0.39

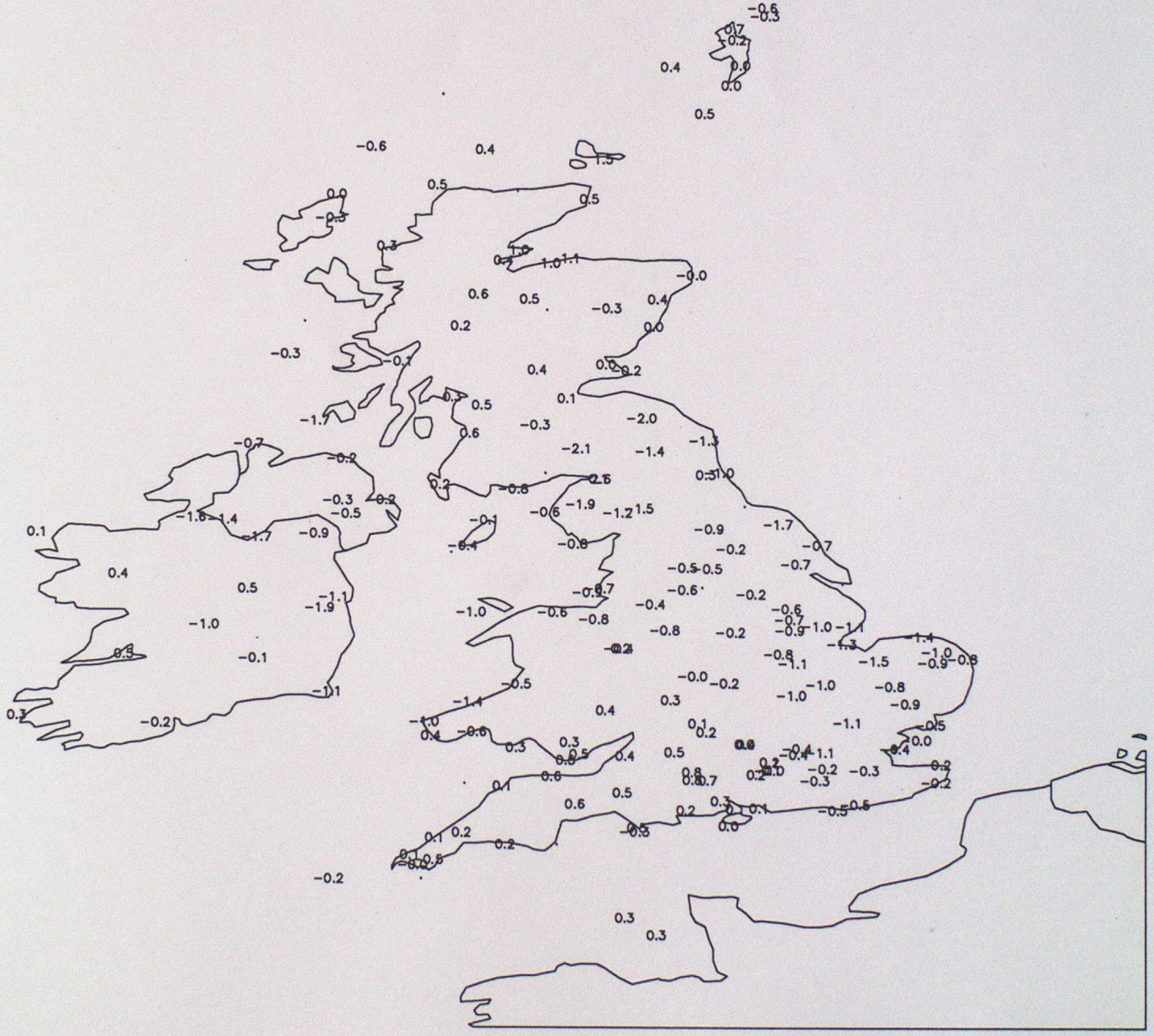
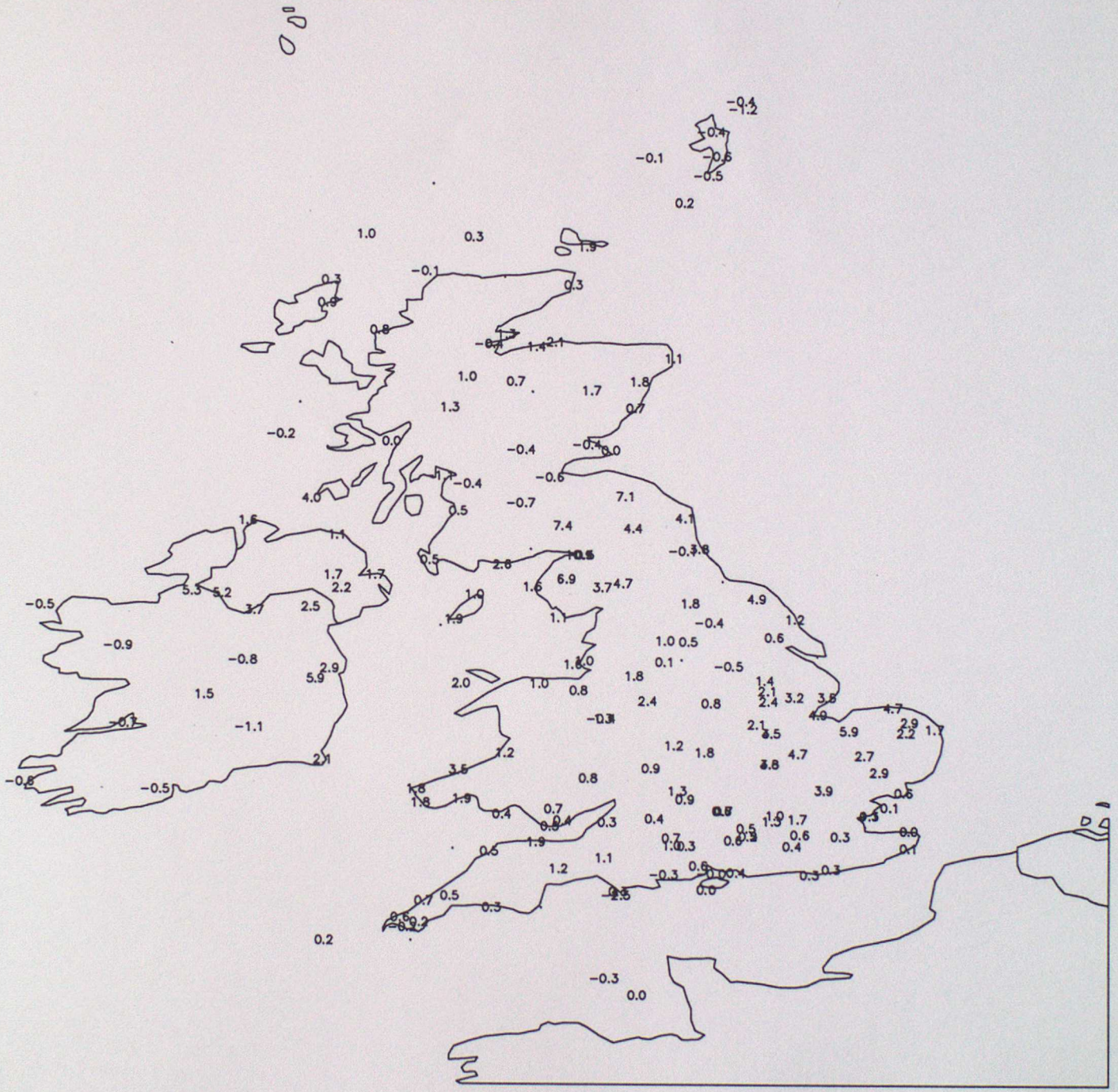


Figure 6.

Global Model : September 92 : Pressure

kurtosis = 1.59